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A SYSTEM FOR LIQUID PROPELLANT GUN DATA REDUCTION ON A HEWLETT---ETC(U)

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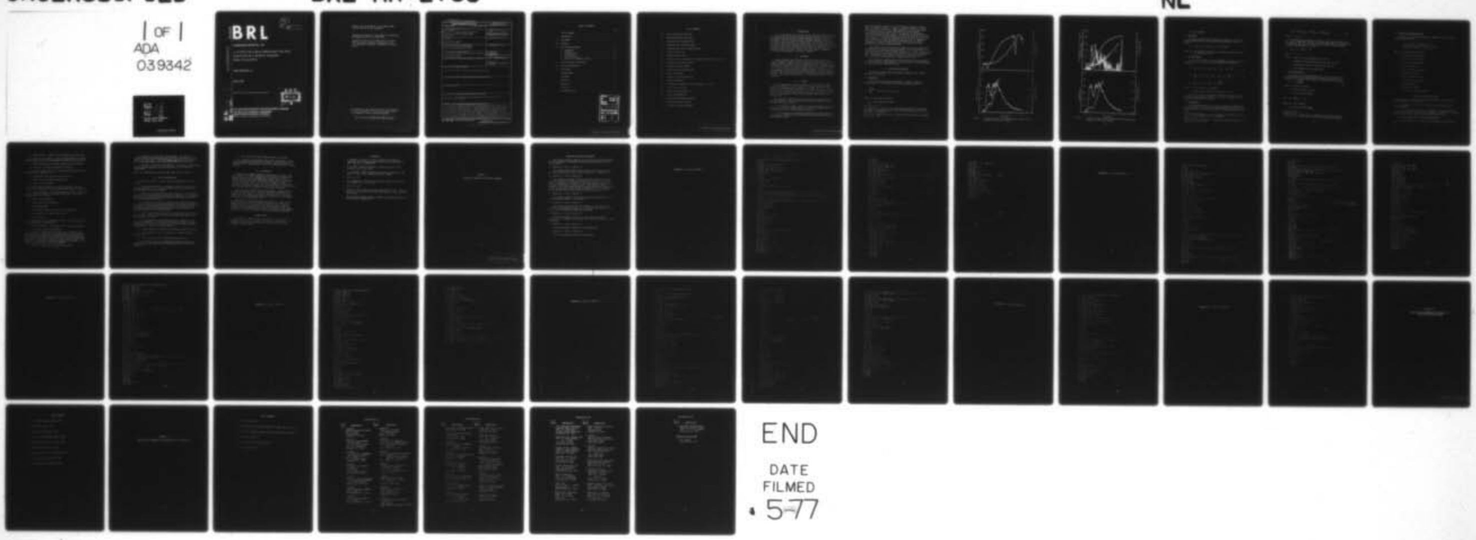

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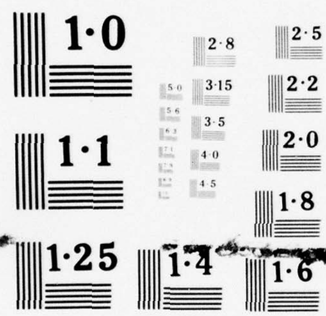

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MEMORANDUM REPORT NO. 2735

A SYSTEM FOR LIQUID PROPELLANT GUN DATA REDUCTION ON A HEWLETT-PACKARD 9830A CALCULATOR

LeRoy Stansbury, Jr.

March 1977

USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) srf A series of computer programs have been developed for the reduction of liquid propellant gun data to aid in the interpretation, study, and evaluation of liquid propellant gun phenomena. These programs are written in the BASIC computer language and are designed specifically to run on a Hewlett-Packard 9830A calculator. The specific design features of these programs are to reduce and to plot gun pressure and projectile velocity; to compute and to plot the fraction of propellant burned, projectile acceleration, projectile displacement, cavity penetration, and the projectile base pressure all as functions of time.		

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LIST OF SYMBOLS

Ap	Area of projectile base (m^2)
C	Propellant charge volume (m^3)
E	Propellant gas covolume (m^3/kg)
F	Propellant force constant (J/kg)
G	Propellant gas ratio of specific heats
M	Projectile mass (kg)
P	Chamber pressure (MPa)
P1	Position of base of projectile relative to breech face of gun (m)
PB	Projectile base pressure (MPa)
R	Propellant density (kg/m^3)
SS	Projectile start of motion (ms)
T_c	Taylor coefficient
U	Internal volume of primer (m^3)
Vo	Chamber volume (m^3)
Vs	The number of desired velocity smoothings (1, 3 or 9)
Vc	Cavity velocity (m/sec)
Xp	Projectile displacement (m)
Xc	Cavity displacement (m)
a	Projectile acceleration (m/sec^2)
v	Projectile velocity (m/sec)
ϕ	Fraction of propellant burned

I. INTRODUCTION

In a continuing effort to reduce the cost and turn-around time for the reduction of liquid propellant gun interior ballistics data, a series of computer programs, written in BASIC computer language, have been developed to run on a Hewlett-Packard (HP) 9830A calculator with only 3808 memory spaces available for instructions. The programs have been designed to reduce digitized gun chamber pressures (P) and velocities (v); to compute projectile acceleration (a), projectile displacement (x), cavity penetration (Xc), projectile base pressure (P_B), and the fraction-of-propellant burned (ϕ), and, to plot, scale, and label all parameters. A listing of all programs is provided in Appendix A.

II. BACKGROUND

Liquid propellant gun ballistics data, in the past, have been reduced and plotted using the Ballistic Research Laboratories' Scientific Computer (BRLESC); however, several problems exist with reducing data on BRLESC and among them are cost and turn-around time. To address these two problems, a series of computer programs have been developed to reduce and to plot ballistic data on an HP 9830A calculator. Because of the limited memory available on the HP 9830A calculator, special programming procedures had to be developed to facilitate the desired data reduction analysis. The purpose of this report is to summarize the data reduction procedures.

III. APPROACH

Seven program files have been created, on two HP cassette tapes (tape no. 1 and tape no. 2), to store the programs required to reduce, compute, and plot all desired parameters. In addition to the seven program files created, five data files were created for storing parameters which are used for additional computations and/or for plotting. These programs are designed to reduce liquid propellant gun pressure and velocity data.

The reduction of pressure data does not present any particular problems, however, several problems are encountered reducing velocity data and they are as follows:

1. At firing pin contact, there is a voltage discharge (across the primer) pulse which is induced onto the velocity-time signal that may be falsely read as the start-of-projectile motion.

2. As the projectile approaches the muzzle of the gun there may be sufficient gas leakage past the projectile that velocity measurements are temporarily lost.

These two problems, inherent in the recording of projectile velocity data, are shown in Figure 1. Figure 1, a composite graph of a liquid propellant round, shows that at approximately 0.5 milliseconds there is an average velocity of about 300 meters per second and the projectile has hardly begun to move. In addition, at approximately 3-3.6 milliseconds (near the muzzle), the velocity drops off by a factor of about two. It has been assumed that neither of these two events are real. Therefore, a scheme has been devised to search for them and to linearly fill in the data gaps before differentiating, to compute acceleration. Figure 2 shows the results of having replaced the questionable data before differentiating.

Both Figures 1 and 2 are composite graphs of the same round showing the projectile displacement (Xp), and velocity (v); the fraction of propellant burned (ϕ); and the chamber pressure (P). Figure 2 additionally shows the projectile acceleration (a) and the Taylor cavity penetration (Xc). The velocity data, shown in both figures, have been smoothed nine times before differentiating to compute acceleration.[1]

The fraction of propellant burned and the Taylor cavity penetration are based on physical approximation. The calculations of these parameters are discussed in the following section.

IV. DATA REDUCTION METHODS

The numerical data reduction procedures employed in the various programs are as follows:

A. Integration

The velocity-time data are integrated, to compute projectile displacement (x), by using the Newton-Cotes quadrature formula:[2]

$$\int_{x_0}^{x_{max}} y\,dx = h/3\ (v_o + 4v_1 + v_2) \qquad (1)$$

where x_o = 0 at shot start (SS)

x_{max} = total projectile travel

---

[1] *L. Stansbury, Jr. and R.H. Comer, "Electronic and Numerical Techniques for Reducing Noisy Gun Ballistic Data," BRL Memorandum Report No. 2492, June 1975. (AD #B006145L)*

[2] *W. E. Milne, "Numerical Calculus," Princeton University Press, Princeton, NJ, P. 123, (1947).*

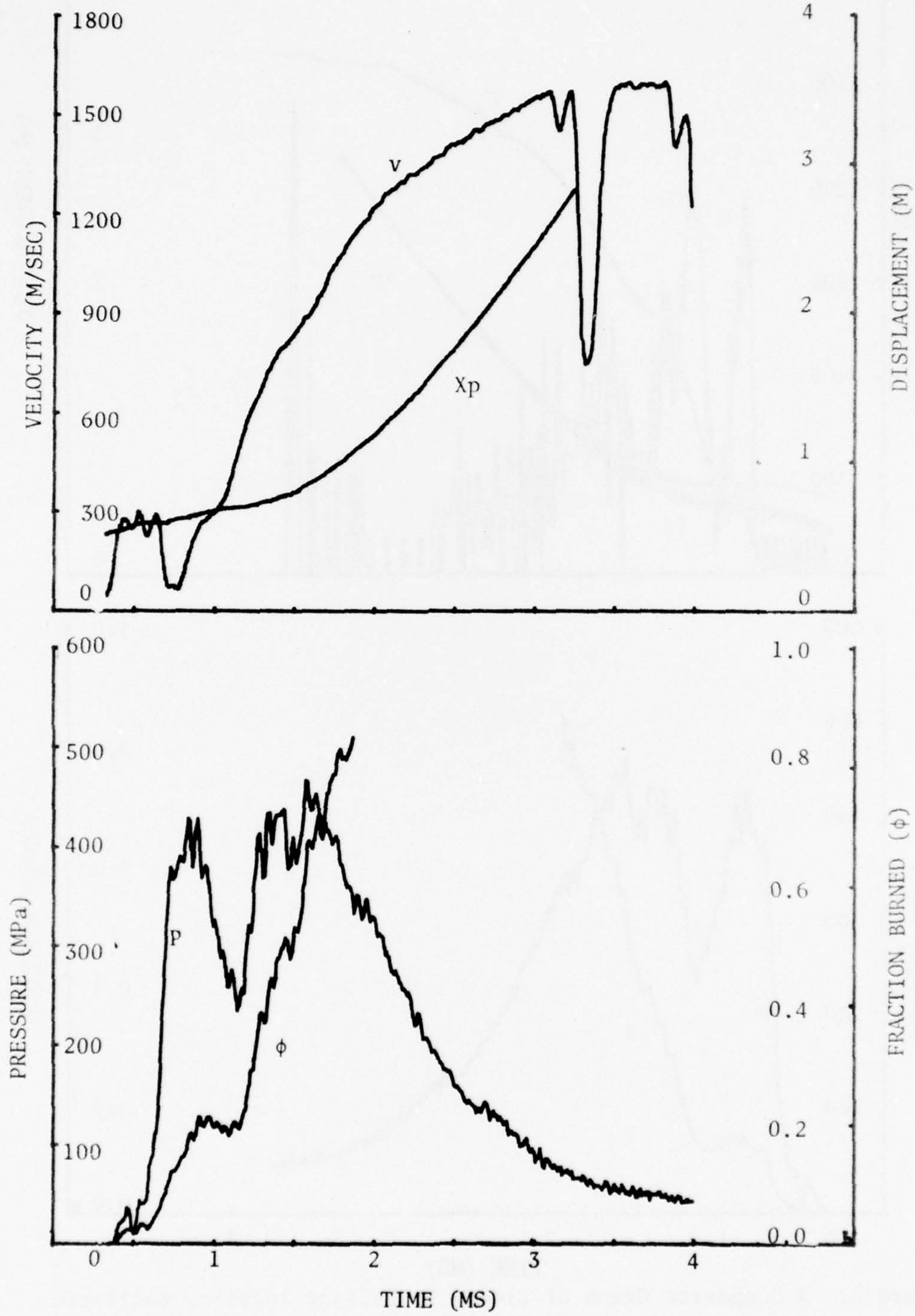

Figure 1. A Composite Graph of Liquid Propellant Interior Ballistic Parameters for Round No. 198/59.

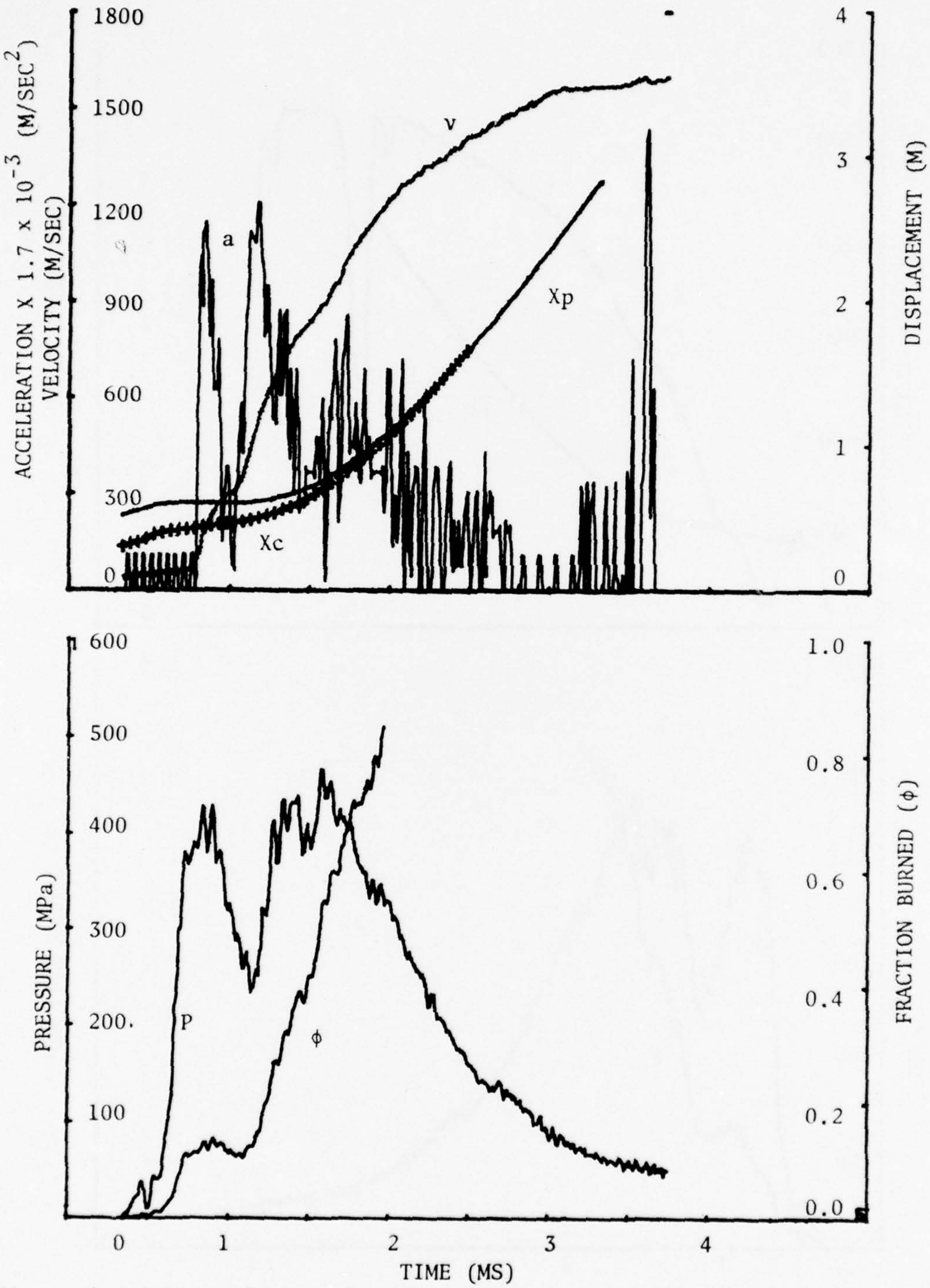

Figure 2. A Composite Graph of Liquid Propellant Interior Ballistic Parameters for Round No. 198/59.

h = time increment

B. Smoothing

The velocity-time data are smoothed one, three, or nine times, before differentiation, using a moving arc polynomial[3] over five points:

$$\bar{y}_3 = (-3(v_1 + v_5) + 12(v_2 + v_4) + 17(v_3))/35 \quad (2)$$

where $\bar{y}_3$ = the smoothed velocity point, evaluated at the mid-point of the five point spread.

C. Differentiation

The velocity-time data was differentiated, to compute projectile acceleration, by using the five point numerical differentiation formulas:[4]

$$y_0' = \frac{1}{12h} (-25y_0 + 48y_1 - 36y_2 + 16y_3 - 3y_4) + \frac{h^4}{5} y^5 \quad (3)$$

$$y_1' = \frac{1}{12h} (-3y_0 - 10y_1 + 18y_2 - 6y_3 + y_4) - \frac{h^4}{20} y^5 \quad (4)$$

$$y_2' = \frac{1}{12h} (y_0 - 8y_1 + 8y_3 - y_4) + \frac{h^4}{30} y^5 \quad (5)$$

where y' = first derivative of velocity

y_n = number of nth velocity data point ($n = 0$ to 4)

Equations (3) and (4) are used to compute the first and second acceleration data points. Equation (5) is used to compute all the remaining acceleration data points.

D. Interpolation

The integration formula (1) is used to compute the odd numbered displacement (x) points and the following three point Lagrangian interpolation formula[5] is used to determine the even numbered displacement points:

---

[3] *J. K. Sterrett, Manual for Moving Polynomial Arc Smoothing, BRL Report No. 840, p. A54, November 1952. (AD #109844)*
[4] *Ibid. 2, p. 97.*
[5] *T. B. Hildebrand, Introduction to Numerical Analysis, McGraw-Hill Book Company, Inc., p. 70, 1956.*

$$x_{(i)} = 0.125x_{(i-1)} + 0.75x_{(i+1)} + 0.375x_{(i+3)} \quad (6)$$

where i = 2, 4, 6 . . .

As the projectile approaches the muzzle, there may be a fall-off in the velocity signal due, in part, to ionized gases ahead of the projectile. To bridge the data gap, the following first order divided differences interpolating polynomial[6] is used:

$$y_{i+1} = y_i + D1[x_{i+1} - x] \quad (7)$$

where i = 0, 1, ... m

and D1 = ratio of first differences of y's and x's

y_i = dependent variable preceding velocity data fall-off

x = independent variable at velocity data fall-off

m = total number of missing data points

E. Cavity Penetration

The velocity (V_c) and displacement (X_c) of the gas cavity penetrating into the moving liquid charge are computed following the procedures outlined by Comer, Shearer and Jones[7] and are as follows:

$$V_c = TC\sqrt{R1*a} \quad (8)$$

where TC = Taylor coefficient

R1 = radius of apex of cavity

a = projectile acceleration

and, $X_c = (\sum V_c \Delta t) + X_p$

where Δt = time increment

X_p = projectile displacement

[6] *Ibid. 2, p. 210.*

[7] *R. H. Comer, R. N. Jones and R. B. Shearer, "Interior Ballistic of Liquid Propellant Guns," BRL Report No. 1205, May 1963 (AD #344042).*

F. Fraction of Propellant Burned

The fraction of propellant burned was computed using the following energy balance equation.[7]

$$\phi = \frac{P/(\gamma-1)\ [V_o+Ax] + \frac{1.1}{2}[M + C]\ v^2}{[(C\lambda/(\gamma-1)) + \frac{1.1}{2}\ CV^2 - (PC/\gamma-1)\ (1/\rho-\eta)]} \tag{9}$$

where P = average chamber pressure

V_o = internal volume of primer

A = area of projectile base

X = projectile displacement

M = mass of projectile

C = mass of propellant charge

V = projectile velocity

γ = ratio of specific heats

λ = propellant force constant

ρ = propellant density

η = propellant covolume

Φ = fraction of propellant burned

V. HP9830A REDUCTION PROCEDURES

The step-by-step procedures for reducing ballistic data, using the HP9830A calculator, are as follows:

1. Load file 4 of tape no. 1; mount a digitized data tape and enter RUN-EXECUTE.

2. Obtain coefficients from a 2° polynomial fit of pressure (MPa) and velocity (m/s) per calibration step (counts); data points to be fitted will be printed-out. Program computes pressure and velocity.

3. Rerun program after obtaining coefficients.

4. Mount tape no. 2 and enter a 1 when requested by the machine (HP).

5. Enter Scratch A - EXECUTE into the machine and rewind tape.

6. Load file 2, of tape no. 2 and enter RUN-EXECUTE into machine. Program computes projectile displacement and stores data into file 4.

7. Rewind tape and enter Scratch A-EXECUTE into the machine.

8. Load file 3 and enter RUN-EXECUTE into machine.

a. Program computes fraction of propellant burned and stores the data into file 7 of tape no. 2.

b. See Appendix B for required input parameters.

9. Enter Scratch A-EXECUTE and rewind tape.

10. Load file 6 and EXECUTE.

11. Mount graph or drop-out blue paper on plotter, with pen positioned over upper-half of page, leaving enough margin for labeling.

12. Enter Run-EXECUTE. The program smooths velocity x-times, plots velocity, computes and plots acceleration, and scales velocity and acceleration (V_s = 1, 3 or 9).

13. Enter Scratch A-EXECUTE.

14. Enter load file 9 and EXECUTE.

15. Enter RUN-EXECUTE.

a. The program computes and plots cavity penetration.

b. See Appendix C for required input data.

16. Enter Scratch A.

17. Enter load file 5 and EXECUTE; however, do not touch plotter until requested by the machine (HP).

18. Enter RUN-EXECUTE. The program (file 5) does the following:

a. Plots and scales the displacement.

b. Requests a "Move Pen Down on Page" to plot pressure and fraction burned, (the pen move is accomplished by pressing the "Lower left" plotter key board key, then lowering the pen to approximately line forty-eight of the drop-out blue). Ninety seconds are provided for the move. This move is required because a sheet of paper, on the plotter, is divided into two pages to accommodate two graphs (x, v, a, Xc on top graph; P and ϕ on the bottom graph).

c. Plots and scales pressure and fraction burned.

d. Requests a "Move Pen Out for P-Labeling." This move is accomplished by pressing the lower left plotter key and moving the pen left to the outer margin; then, press upper right plotter key and move pen to the right margin (ninety seconds are provided for the move).

e. Requests a "Move Pen Up for Labeling." This move is accomplished by pressing the lower left key and moving pen up to full extent of potentiometer.

NOTE: For subsequent runs, for the same round, start at item no. 9.

VI. SPECIAL PROGRAM NOTES

As an aid to the user, a series of special program notes are as follows:

1. The appropriate Reel No. and Round No. have to be put into the program stored in file 5, lines 320 and 330, respectively, for them to be plotted onto the composite graphs.

2. After nine smoothings and mid-point evaluations, of the velocity data, the first eighteen data points are lost; therefore, it is imperative that the velocity reduction be started ahead of the time of shot start by at least eighteen data points.

3. For the test case (reel 198, ident 98) the velocity reduction was started at the first digitized data point of the data block containing the velocity data and shot-start was picked at .33 ms (shot start was selected from the raw data printed out as the first data point that positively departs from the zero baseline).

4. Time is measured relative to the first data point of the second block of data. This was done to prevent using additional memory space searching for the fiducial.

5. The displacement data are multiplied by a factor of 100, at the time of computation, in order that they could be stored as integer numbers and not lose accuracy at the start of travel; however, the data are reduced by a factor of ten before plotting.

6. Program changes are required if new plotting scales are desired.

7. The acceleration scale is a factor of 1.7 greater than the velocity scale.

8. All plotted scales are labeled except the time scale.

9. The velocity data may be smoothed once, three or nine times. (Each smoothing takes approximately one minute and fifty seconds to be completed).

10. Only every fifth cavity penetration point is plotted.

11. A search is made of the velocity data to determine at which point the data drops out and when it returns. These two prints are saved and linear interpolation is used to provide data points to bridge the gap.

VII. CONCLUSIONS

The series of computer programs, presented in this report, have been written in the BASIC language and are designed to reduce and to display digitized liquid propellant gun ballistic data, using an HP9830A calculator with only 3808 memory spaces available for program instructions. These series of programs are designed to reduce ballistic parameters (Xp, v, a, P, ϕ, and Xc) previously reduced and displayed on the BRLESC computer, which required 55K (72 bits/word) memory spaces be available for program instructions and storing data.

The total time required to reduce and display a composite graph of desired parameters, for a round, is approximately two hours as compared to forty minutes on the BRLESC computer; however, the turn-around time, for completing the reduction and display, on the HP9830A calculator, can be considerably less.

The reduction of liquid propellant gun ballistics data on the HP9830A calculator offers two distinct advantages over reductions on BRLESC and they are, (1) reduced turn-around time and (2) reduced computational cost. However, due to the limited memory spaces, data reduction on the HP9830A calculator requires considerably more operator interaction, with the calculator, than would otherwise be necessary.

ACKNOWLEDGMENT

The author is indebted to Mr. Robert Martz, of the Mechanics and Structures Branch, for his ingenuity and electronic expertise in developing a system for digitizing and storing ballistic data onto HP digital cassette tapes.

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1. L. Stansbury, Jr. and R. H. Comer, "Electronic and Numerical Techniques for Reducing Noisy Gun Ballistic Data," BRL Report No. 2492, June 1975. (AD #B006145L)

2. W. E. Milne, "Numerical Calculus," Princeton University Press, Princeton, NJ, p. 123, (1947).

3. J. K. Sterrett, "Manual for Moving Polynomial Arc Smoothing," BRL Report No. 840, p. A54, November 1952. (AD #109844)

4. Ibid. 2, p. 97.

5. T. B. Hildebrand, Introduction to Numerical Analysis, McGraw-Hill Book Company, Inc., p. 70, 1956.

6. Ibid. 2, p. 210.

7. Richard H. Comer, Robert B. Shearer and Richard N. Jones, "Interior Ballistic of Liquid Propellant Guns," BRL Report No. 1205, May 1963 (AD #344042).

8. Operating and Programming Manual, Hewlett-Packard 9830A Calculator, Hewlett-Packard Company, 1973.

APPENDIX A.

LISTINGS OF REDUCTION AND PLOTTING PROGRAMS

REDUCTION AND PLOTTING PROGRAMS

The computer programs, required to reduce and plot liquid propellant gun ballistic data, on a HP9830A calculator, and the functions of each are as follows:

A. Program No. 1 (File 4, Tape No. 1)

This program reduces digitized pressure (p) and velocity (v) data and stores the data into files 0 and 1, of tape no. 2, respectively.

B. Program No. 2 (File 2, Tape No. 2)

This program is designed to search the velocity-time data for the points at which there is data drop-out and when it returns. A second search is conducted for the points at which the voltage discharge across the primer interrupts the velocity trace. The program is further designed to use a first order divided difference interpolating polynomial to fill the data gaps before projectile displacement (x) is computed. The displacement data is then stored into file 4 of tape no. 2.

C. Program No. 3 (File 3, Tape No. 2)

This program computes, "the fraction-of-propellant burned" (ϕ) and stores the data into file 7 of tape no. 2.

D. Program No. 4 (File 5, Tape No. 2)

This program plots and scales displacement (x), pressure (P) and the fraction of propellant burned (ϕ). The program also labels x, a, v, P and ϕ scales and plots the round identification.

E. Program No. 5 (File 6, Tape No. 2)

This program smooths velocity (1, 3 or 9 times) and computes acceleration. In addition, the program plots and scales the velocity and acceleration.

F. Program No. 6 (File 9, Tape No. 2)

This program computes and plots cavity penetration.

G. Program No. 7 (File 10, Tape No. 2)

This program computes projectile base pressure.

PROGRAM NO. 1 (FILE 4; TAPE NO. 1)

```
10 DIM TI[256,2],C[6],B[6],PI[256,2],VI[256,2]
20 Q=M=1
30 W1=0
40 DISP "TMIN-RAW DATA(MS)";
50 INPUT T8
60 DISP "TMAX-RAW DATA(MS)";
70 INPUT T9
80 DISP "DATA START BLOCK(#)";
90 INPUT C9
100 W2=W3=G=0
110 N=1
120 Z=0
130 IF (N >= 7) THEN 1290
140 GOTO 160
150 WAIT 30000
160 X=0
170 LOAD  DATA N,T
180 B[1]=B[2]=B[3]=B[4]=B[5]=B[6]=0
190 J=1
200 I=1
210 B[1]=(T[J+25,I]+T[J+26,I]+T[J+27,I]+T[J+28,I]+T[J+29,I]+T[J+30,I])/6
220 B[2]=(T[J+85,I]+T[J+86,I]+T[J+87,I]+T[J+88,I]+T[J+89,I]+T[J+90,I])/6
230 B[3]=(T[J+160,I]+T[J+161,I]+T[J+162,I]+T[J+163,I]+T[J+164,I]+T[J+165,I])/6
240 B[4]=(T[J+225,I]+T[J+226,I]+T[J+227,I]+T[J+228,I]+T[J+229,I]+T[J+230,I])/6
250 I=2
260 B[5]=(T[J+25,I]+T[J+26,I]+T[J+27,I]+T[J+28,I]+T[J+29,I]+T[J+30,I])/6
270 B[6]=(T[J+90,I]+T[J+91,I]+T[J+92,I]+T[J+93,I]+T[J+94,I]+T[J+95,I])/6
280 B[2]=B[2]-B[1]
290 B[3]=B[3]-B[1]
300 B[4]=B[4]-B[1]
310 B[5]=B[5]-B[1]
320 B[6]=B[6]-B[1]
330 L=0
340 B9=B[1]
350 B[1]=0
360 IF (N >= 5) THEN 390
370 DISP "MPA/STEP ";
380 GOTO 400
390 DISP "MPS/CAL STEP";
400 INPUT C[2]
410 FOR I=1 TO 6
420 C[I]=C[2]*L
430 L=L+1
440 NEXT I
450 FOR I=1 TO 6
460 PRINT C[I]"MPA OR MPS",B[I]"CTS"
470 NEXT I
480 PRINT B9
490 IF (C9=2) THEN 510
500 GOTO 530
510 N=N+1
520 GOTO 560
530 IF (C9=3) THEN 550
540 GOTO 560
550 N=N+2
560 LOAD  DATA N,T
570 FOR I=1 TO 3
580 DISP "CAL L.S. COEFF"I;
590 INPUT F[I]
600 PRINT F[I]
```

```
610 NEXT I
620 PRINT
630 PRINT
640 P=T1=V=D=D1=0
650 IF (N >= 5) THEN 700
660 SCALE 0,8,0,80000/145
670 XAXIS 0,1
680 YAXIS 0,10000/145
690 GOTO 730
700 SCALE 0,8,0,6000/10
710 XAXIS 0,1
720 YAXIS 8,1000/10,0,6000/10
730 GOTO 740
740 FOR I=1 TO 2
750 FOR J=1 TO 256
760 T1=T1+0.01
770 T[J,I]=T[J,I]
780 IF (T1 >= T8) THEN 810
790 NEXT J
800 NEXT I
810 PRINT J,I
820 W2=J
830 W1=I
840 T1=T1
850 FOR I=W1 TO 2
860 FOR J=W2 TO 256
870 IF (N >= 5) THEN 940
880 P[Q,M]=(F[1]+(F[2]*(T[J,I]-B9))+(F[3]*(T[J,I]-B9)↑2))
890 IF (J=256) THEN 910
900 GOTO 930
910 J=1
920 I=2
930 GOTO 1000
940 V[Q,M]=(F[1]+(F[2]*(T[J,I]-B9))+(F[3]*(T[J,I]-B9)↑2))/10
950 IF (J=256) THEN 970
960 GOTO 1000
970 J=1
980 I=2
990 T1=T1+0.01
1000 T1=T1+0.01
1010 IF (T1<0.01) THEN 1170
1020 IF (T1 >= T9) THEN 1200
1030 IF (N >= 5) THEN 1080
1040 PLOT T1,P[Q,M]
1050 GOTO 1070
1060 PRINT T1,P[Q,M],Q,M,J,I
1070 GOTO 1110
1080 PLOT T1,V[Q,M]
1090 GOTO 1110
1100 PRINT T1,V[Q,M]
1110 IF (T1=T9) THEN 1280
1120 IF (Q=256) THEN 1140
1130 GOTO 1160
1140 Q=0
1150 M=2
1160 GOTO 1170
1170 Q=Q+1
1180 NEXT J
1190 NEXT I
1200 PEN
```

```
1210 N=N+1
1220 IF (N >= 5) THEN 1260
1230 N=N+1
1240 GOTO 1220
1250 PEN
1260 Q=M=1
1270 GOTO 120
1280 PEN
1290 DISP "MNT #2 TPE;INPT 1 AFTER";
1300 INPUT I9
1310 T1=0.01
1320 STORE  DATA 0,P
1330 STORE  DATA 1,V
1340 P[1,1]=P[2,1]
1350 V[1,1]=V[2,1]
1360 FOR I=1 TO 2
1370 FOR J=1 TO 256
1380 PRINT T1,P[J,I],V[J,I]
1390 T1=T1+0.01
1400 IF (T1 >= T9) THEN 1430
1410 NEXT J
1420 NEXT I
1430 END
```

PROGRAM NO. 2 (FILE 2; TAPE NO. 2)

```
10 DIM VI[256,2],XI[256,2]
20 C=0
30 X=0
40 T1=0
50 LOAD  DATA 1,V
60 DISP "VEL DIP(?);1=YES,2=NO";
70 INPUT D9
80 IF (D9=1) THEN 100
90 GOTO 120
100 GOSUB 990
110 GOTO 120
120 C=0.00001*0.333
130 DISP "SHOT START(MS)";
140 INPUT S2
150 S2=S2/0.01
160 DISP "PRINTING(?)-YES=1,NO=2";
170 INPUT P1
180 DISP "TMAX(MS)";
190 INPUT T9
200 X[1,1]=0
210 DISP "FRNT-ND PROB(?);1=Y,2=N";
220 INPUT F9
230 IF (F9=1) THEN 250
240 GOTO 260
250 GOSUB 1460
260 FOR I=1 TO 2
270 FOR J=1 TO 256
280 V[J,I]=V[J,I]*10
290 IF (P1=1) THEN 310
300 GOTO 320
310 PRINT T1,V[J,I]
320 T1=T1+0.01
330 IF (T1 >= T9) THEN 360
340 NEXT J
350 NEXT I
360 J=S2
370 I=1
380 DISP "XMAX*10(M ) ";
390 INPUT X9
400 T1=0+(S2*0.01)
410 Q=3
420 L=1
430 X[Q,L]=X[Q-2,L]+(C*(V[J,I]+4*V[J+1,I]+V[J+2,I]))*100
440 IF (J >= 253) THEN 500
450 IF (Q=255) THEN 560
460 IF (X[Q,L] >= X9) THEN 620
470 J=J+2
480 Q=Q+2
490 GOTO 430
500 Q=Q+2
510 X[Q,L]=X[Q-2,L]+(C*(V[256,1]+4*V[1,2]+V[2,2]))*100
520 J=2
530 I=2
540 Q=Q+2
550 GOTO 430
560 J=J+2
570 X[1,2]=X[255,1]+(C*(V[J,I]+4*V[J+1,I]+V[J+2,I]))*100
580 J=J+2
590 Q=3
600 L=2
```

```
610 GOTO 430
620 Q=2
630 L=1
640 X[2,1]=-0.125*X[5,1]+0.75*X[3,1]+0.375*X[1,1]
650 Q=Q+2
660 X[Q,L]=-0.125*X[Q-3,L]+0.75*X[Q-1,L]+0.375*X[Q+1,L]
670 IF (Q+1=255) THEN 710
680 IF (X[Q,L] >= X9-0.25) THEN 810
690 Q=Q+2
700 GOTO 660
710 Q=Q+2
720 X[Q,L]=-0.125*X[253,1]+0.75*X[255,1]+0.375*X[1,2]
730 Q=2
740 L=2
750 X[Q,L]=-0.125*X[255,1]+0.75*X[1,2]+0.375*X[3,2]
760 Q=Q+2
770 X[Q,L]=-0.125*X[Q-3,L]+0.75*X[Q-1,L]+0.375*X[Q+1,L]
780 Q=Q+2
790 IF (X[Q,L] >= X9-0.25) THEN 810
800 GOTO 770
810 STORE  DATA 4,X
820 IF (P1=1) THEN 840
830 GOTO 980
840 U=1
850 Z=S2
860 FOR I=1 TO 2
870 FOR J=1 TO 256
880 PRINT X[J,I],T1,V[Z,U]
890 IF (Z=256) THEN 910
900 GOTO 930
910 U=2
920 Z=0
930 T1=T1+0.01
940 IF (X[J,I] >= X9) THEN 980
950 Z=Z+1
960 NEXT J
970 NEXT I
980 STOP
990 I=Q=1
1000 J=50
1010 Q=50
1020 E=1
1030 IF (ABS(V[J+13,E]-V[J,I]) >= 87.8) THEN 1080
1040 J=J+1
1050 Q=Q+1
1060 IF ((J+13)=257) THEN 1080
1070 GOTO 1030
1080 G=1
1090 IF (ABS(V[G,2]-V[J,I]) >= 87.8) THEN 1180
1100 G=G+1
1110 Q=Q+1
1120 J=J+1
1130 IF (J=257) THEN 1150
1140 GOTO 1090
1150 I=2
1160 J=1
1170 GOTO 1090
1180 L=H=0
1190 IF (V[G,2] >= V[J,I]) THEN 1240
1200 L=L+1
```

```
1210 G=G+1
1220 IF (G=257) THEN 1240
1230 GOTO 1190
1240 IF (Q>256) THEN 1260
1250 GOTO 1330
1260 I=2
1270 Q=Q-256
1280 H=G-Q
1290 Y1=Y2=B1=0
1300 X1=X1=X3=0
1310 D1=D2=N1=0
1320 F1=F2=0
1330 X2=Q-(Q+H)
1340 Y2=(V[Q,I]-V[G,I])/X2
1350 PRINT V[Q,I],V[G,I]
1360 PRINT V[Q,I],Y2
1370 I=2
1380 FOR J=1 TO H-1
1390 V2=Y2*((Q+J)-(Q-0))
1400 B1=V2+V[Q,I]
1410 V[Q+J,I]=B1
1420 PRINT B1,V2
1430 NEXT J
1440 STORE  DATA 1,V
1450 RETURN
1460 I=1
1470 DISP "V+5-V=?";
1480 INPUT J9
1490 K=U=S2
1500 IF (V[K+5,I]-V[U,I]=J9) THEN 1530
1510 K=K+1
1520 GOTO 1500
1530 PRINT V[K+5,I],V[U,I],K
1540 M=5+(K-U)+U
1550 X1=S2-M
1560 H1=M-S2
1570 X2=M-(M+1)
1580 F1=S2-(M+1)
1590 F2=X1-X2
1600 PRINT F2,F1,X2,X1
1610 Y1=(V[S2,I]-V[M,I])/X1
1620 Y2=(V[M,I]-V[M+1,I])/X2
1630 PRINT V[M,I],V[M+1,I]
1640 D1=(Y1-Y2)/F2
1650 PRINT D1,Y2,Y1
1660 FOR J=1 TO H1-1
1670 V1=Y1*((S2+J)-(S2-0))
1680 B1=V1+V[S2,I]
1690 V[S2+J,I]=B1
1700 PRINT B1,V1
1710 NEXT J
1720 STORE  DATA 1,V
1730 RETURN
```

PROGRAM NO. 3 (FILE 3; TAPE NO. 2)

```
10 DIM V[256,2],P[256,2],X[256,2],E[256,2]
20 LOAD  DATA 0,P
30 LOAD  DATA 1,V
40 LOAD  DATA 4,X
50 DISP "PRINTING(?)-YES=1,NO=2";
60 INPUT P1
70 DISP "PRIMER VOL( M3)";
80 INPUT U1
90 DISP "V0( M3)";
100 INPUT V1
110 DISP "M(KG   )";
120 INPUT M
130 DISP "C(KG   )";
140 INPUT C1
150 DISP "GAM";
160 INPUT G1
170 DISP "RHO(KG / M3)";
180 INPUT R1
190 DISP "AREA PROJ(M2 )";
200 INPUT A1
210 DISP "ETA( M3/KG)";
220 INPUT E1
230 DISP "F(J/KG      )";
240 INPUT F1
250 S1=(1/R1)-E1
260 DISP "SS(MS)";
270 INPUT S9
280 S9=(S9-0)/0.01
290 PRINT S9
300 S2=C2=C3=C4=C5=B1=B2=F2=0
310 PRINT "T,FEE,V2,P,V,I"
320 PRINT "MS,-,M2S2,MPA,M/S "
330 G1=G1-1
340 C2=C1/G1
350 C3=C1*F1/G1
360 C4=(1/R1)-E1
370 C5=1/G1
380 T1=0+(S9*0.01)+0.01
390 Z=1
400 E=0
410 FOR I=1 TO 2
420 FOR J=1 TO 256
430 S2=P[S9,Z]*1E+06/G1
440 B1=S2*(U1+(A1*X[J,I]/100))+(0.05638*(M+C1)*((V[S9,Z]*10)↑2))
450 B2=C3+0.05638*C1*((V[S9,Z]*10)↑2)-(S2*C1*C4)
460 E[J,I]=(B1/B2)*1000
470 IF (P1=1) THEN 490
480 GOTO 520
490 WRITE (15,500)T1,E[J,I],(V[S9,Z]*10)↑2,P[S9,Z],V[S9,Z]*10,S9
500 FORMAT F9.2,F9.4,F9.0,F9.0,F9.0,F9.0,F9.0
510 T1=T1+0.01
520 IF (S9 >= 256) THEN 560
530 IF (E[J,I] >= 970) THEN 600
540 S9=S9+1
550 GOTO 580
560 Z=2
570 S9=1
580 NEXT J
590 NEXT I
600 STORE  DATA 7,E
610 STOP
```

PROGRAM NO. 4 (FILE 5; TAPE NO. 2)

```
10 DIM P[256,2],X[256,2],E[256,2]
20 LOAD  DATA 0,P
30 LOAD  DATA 4,X
40 LOAD  DATA 7,E
50 DISP "SS(MS)";
60 INPUT S8
70 DISP "TMAX(MS)";
80 INPUT T9
90 DISP "MAX DISPLACEMENT(M )";
100 INPUT X9
110 S9=(S8-0)/0.01
120 T1=S8
130 SCALE 0,5,0,4
140 XAXIS 0,0.5
150 YAXIS 5,1,0,4
160 DISP "PROJECTILE BASE POS(M )";
170 INPUT P1
180 FOR I=1 TO 2
190 FOR J=1 TO 256
200 PLOT T1,((X[J,I]/100)+P1)
210 IF (X[J,I] >= X9) THEN 250
220 T1=T1+0.01
230 NEXT J
240 NEXT I
250 PEN
260 FOR Y=0 TO 4 STEP 1
270 PLOT 4.4,Y
280 LABEL (290,1.5,1.7,0,10/8)Y
290 FORMAT F4.1
300 NEXT Y
310 DISP "MOVE PEN DOWN ON PAGE";
320 WAIT 90000
330 T1=S8
340 SCALE 0,5,0,600
350 IPLOT 3,500
360 LABEL (*)" REEL 198"
370 LABEL (*)" ID-NO 50 "
380 XAXIS 0,0.5
390 YAXIS 0,100
400 FOR I=1 TO 2
410 FOR J=S9 TO 256
420 PLOT T1,P[J,I]
430 IF (T1 >= T9) THEN 500
440 T1=T1+0.01
450 IF (J=256) THEN 470
460 GOTO 480
470 S9=1
480 NEXT J
490 NEXT I
500 PEN
510 LABEL (*,1.6,1.7,0,10/8)
520 FOR Y=0 TO 600 STEP 100
530 PLOT -1,Y
540 LABEL (550)Y
550 FORMAT F4.0
560 NEXT Y
570 SCALE 0,5,0,1
580 XAXIS 0,0.5
590 YAXIS 5,2/10
600 FOR Y=0 TO 1 STEP 2/10
```

```
610 PLOT 4.4,Y
620 LABEL (630)Y
630 FORMAT F4.1
640 NEXT Y
650 T1=S8+0.01
660 FOR I=1 TO 2
670 FOR J=1 TO 256
680 PLOT T1,E[J,I]/1000
690 IF (E[J,I] >= 999) THEN 730
700 T1=T1+0.01
710 NEXT J
720 NEXT I
730 PEN
740 FOR X=0 TO 5 STEP 1
750 PLOT X,0.02
760 LABEL (780)X
770 NEXT X
780 FORMAT F2.0
790 DISP "MOVE PEN OUT  FOR P-LABELING"
800 WAIT 90000
810 SCALE 0,5,0,4
820 IPLOT 6.5,1.5
830 LABEL (*,2,1.7,PI/2,10/8)"FRACTION BURNED ( )"
840 IPLOT -6.5,0.3
850 LABEL (*,2,1.7,PI/2,10/8)"PRESSURE (MN/M2)"
860 DISP "MOVE PEN UP FOR LABELING"
870 WAIT 90000
880 SCALE 0,5,0,4
890 IPLOT 6.5,1.5
900 LABEL (*,2,1.7,PI/2,10/8)"DISPLACEMENT (M)"
910 IPLOT -6.5,-0.5
920 LABEL (*,2,1.7,PI/2,10/8)"ACCELERATION X1.7E-3(M/SEC2)"
930 IPLOT 0.36,0.3
940 LABEL (*,2,1.7,PI/2,10/8)"VELOCITY (M/SEC)"
950 STOP
```

PROGRAM NO. 5 (FILE 6; TAPE NO. 2)

```
10 DIM V[256,2],Y[256,2],A[256,2]
20 O9=G4=1
30 Y=0
40 DISP "DELTAT=.01MS FOR 100KCDATA";
50 INPUT D1
60 DISP "NO.SMOOTHINGS(1,3,9)";
70 INPUT S8
80 DISP "SS(MS)";
90 INPUT S1
100 C2=1/(12*0.001*D1)
110 DISP "PRINTING(?)-YES=1,NO=2";
120 INPUT B9
130 DISP "TMAX(MS)";
140 INPUT W1
150 LOAD  DATA 1,V
160 SCALE 0,5,0,1800
170 XAXIS 0,0.5
180 YAXIS 0,300
190 FOR Y=0 TO 1800 STEP 300
200 PLOT -1,Y
210 LABEL (220)Y
220 FORMAT F5.0
230 NEXT Y
240 T9=0.02
250 I=1
260 J=O2=U3=3
270 T1=0+T9
280 Y[J,I]=(1/35)*(-3*(V[J-2,I]+V[J+2,I])+12*(V[J-1,I]+V[J+1,I])+17*V[J,I])
290 V[J,I]=Y[J,I]
300 IF (T1 >= S1) THEN 320
310 GOTO 380
320 IF (G4=S8) THEN 340
330 GOTO 380
340 PLOT T1,V[J,I]*10
350 IF (B9=1) THEN 370
360 GOTO 380
370 PRINT T1,V[J,I],J,I
380 T1=T1+0.01
390 J=J+1
400 IF (J=255) THEN 420
410 GOTO 280
420 M=J-2
430 N=J-1
440 U=J+1
450 L=J
460 K=Q=R=O=B=1
470 W=2
480 Y[J,I]=(1/35)*(-3*(V[M,Q]+V[K,W])+12*(V[N,R]+V[U,O])+17*V[L,B])
490 V[J,I]=Y[J,I]
500 IF (G4=S8) THEN 520
510 GOTO 560
520 PLOT T1,V[J,I]*10
530 IF (B9=1) THEN 550
540 GOTO 560
550 PRINT T1,V[J,I],J,I
560 T1=T1+0.01
570 IF (T1 >= W1) THEN 890
580 M=M+1
590 IF (M=257) THEN 710
600 N=N+1
```

```
610 IF (N=257) THEN 740
620 U=U+1
630 IF (U=257) THEN 770
640 L=L+1
650 IF (L=257) THEN 800
660 J=J+1
670 IF (J=257) THEN 830
680 K=K+1
690 IF (K=257) THEN 860
700 GOTO 480
710 M=1
720 O=2
730 GOTO 600
740 N=1
750 R=2
760 GOTO 620
770 U=1
780 O=2
790 GOTO 640
800 L=1
810 B=2
820 GOTO 660
830 J=1
840 I=2
850 GOTO 680
860 K=1
870 W=1
880 GOTO 480
890 PEN
900 IF (Q9=S8) THEN 1100
910 IF (S8=1) THEN 1100
920 IF (S8=3) THEN 940
930 IF (S8=9) THEN 1010
940 Q2=Q2+2
950 G4=G4+1
960 J=Q2
970 I=1
980 T9=T9+0.02
990 Q9=Q9+1
1000 GOTO 270
1010 U3=U3+2
1020 G4=G4+1
1030 J=U3
1040 I=1
1050 T9=T9+0.02
1060 DISP "SMOOTHED Q9=";Q9
1070 WAIT 3000
1080 Q9=Q9+1
1090 GOTO 270
1100 DISP "SS(MS)";
1110 INPUT S1
1120 IF (S8=1) THEN 1150
1130 IF (S8=2) THEN 1170
1140 IF (S8=3) THEN 1190
1150 Z=(S1-0)/D1
1160 GOTO 1200
1170 Z=(S1-0)/D1
1180 GOTO 1200
1190 Z=(S1-0)/D1
1200 M2=Z
```

```
1210 A[1,1]=(C2*(-25*V[1,1]+48*V[2,1]-36*V[3,1]+16*V[4,1]-3*V[5,1]))/100
1220 IF (A[1,1]<0) THEN 1240
1230 GOTO 1250
1240 A[1,1]=0
1250 A[2,1]=(C2*(-3*V[1,1]-10*V[2,1]+18*V[3,1]-6*V[4,1]+V[5,1]))/100
1260 IF (A[2,1]<0) THEN 1280
1270 GOTO 1290
1280 A[2,1]=0
1290 PRINT S1+0.02,A[1,1]
1300 PRINT S1+0.03,A[2,1]
1310 N=2
1320 I=1
1330 E=1
1340 J=1
1350 T1=S1
1360 A[J+N,I]=(C2*(V[Z,E]-8*V[Z+1,E]+8*V[Z+3,E]-V[Z+4,E]))/100
1370 IF (T1 >= W1) THEN 1540
1380 T1=T1+D1
1390 IF (A[J+N,I]<0) THEN 1410
1400 GOTO 1420
1410 A[J+N,I]=0
1420 IF (Z=256-M2+1) THEN 1470
1430 IF (J=254) THEN 1500
1440 Z=Z+1
1450 J=J+1
1460 GOTO 1360
1470 E=2
1480 Z=1
1490 GOTO 1360
1500 J=1
1510 I=2
1520 N=0
1530 GOTO 1360
1540 STORE  DATA 8,A
1550 T1=S1+D1
1560 SCALE 0,5,0,3000
1570 XAXIS 0,0.5
1580 YAXIS 0,500
1590 FOR I=1 TO 2
1600 FOR J=1 TO 256
1610 IF (B9=1) THEN 1630
1620 GOTO 1640
1630 PRINT T1,A[J,I],V[J,I]
1640 IF (T1 >= S1) THEN 1660
1650 GOTO 1670
1660 PLOT T1,A[J,I]
1670 IF (T1 >= W1) THEN 1710
1680 T1=T1+D1
1690 NEXT J
1700 NEXT I
1710 PEN
1720 STOP
```

PROGRAM NO. 6 (FILE 9; TAPE NO. 2)

```
10 DIM A[256,2],X[256,2],C[250],B[250]
20 LOAD  DATA 4,X
30 LOAD  DATA 8,A
40 DISP "TAYLOR COEF.";
50 INPUT T2
60 C5=0.001*0.01
70 DISP "CAVITY RADIUS(M )";
80 INPUT R1
90 DISP "BORE AREA(CM2)";
100 INPUT A1
110 DISP "PROJ BASE POS.(M )";
120 INPUT B1
130 DISP "SHOT START(MS)";
140 INPUT S1
150 DISP "CAVITY INITIATION(M )";
160 INPUT C8
170 DISP "PRINTING(?),1=YES,2=NO";
180 INPUT P1
190 S9=(S1-0)/0.01
200 A=0
210 X=0
220 C9=0
230 J=S9
240 I=H=1
250 C[1]=B[1]=0
260 Q=2
270 T1=S1+0.01
280 C[Q]=C5*(T2*SQR(R1*A[J,I]*1000))+C[Q-1]
290 B[Q]=C[Q]+C8+(X[Q,I])
300 IF (P1=1) THEN 320
310 GOTO 330
320 PRINT T1,C[Q],B[Q],(X[Q,I])+B1
330 X[Q,I]=X[Q,I]
340 T1=T1+0.01
350 H=H+1
360 IF (B[Q] >= (X[Q,I]/100)+B1) THEN 440
370 J=J+1
380 Q=Q+1
390 IF (J=257) THEN 410
400 GOTO 280
410 I=2
420 J=1
430 GOTO 280
440 SCALE 0,5,0,4
450 T1=S1
460 FOR I=2 TO H STEP 5
470 PLOT T1,B[I]
480 CPLOT -0.3,-0.3
490 LABEL (*)"+"
500 T1=T1+0.05
510 NEXT I
520 PEN
530 END
```

PROGRAM NO. 7 (FILE 10; TAPE NO. 2)

```
10 DIM A[256,2],B[256,2],P[256,2],F[256,2]
20 LOAD  DATA 0,P
30 LOAD  DATA 7,F
40 LOAD  DATA 8,A
50 DISP "PROJ WEIGHT(G )";
60 INPUT M
70 M=M/453.6
80 DISP "SHOT START(MS)";
90 INPUT S1
100 DISP "CHARGE WT(G )";
110 INPUT C
120 C=C/453.6
140 T1=S1+0.01
150 Q=(S1)/0.01
160 DISP "BORE AREA( M2)";
170 INPUT A1
180 A1=A1/6.4516E-04
190 PRINT "   T1                   BP(M)              P                      BP(M+C+F)
200 PRINT "   MS                    MPA               MPA                       MPA"
210 K=0
220 E=1
230 FOR I=1 TO 2
240 FOR J=1 TO 256
250 B[J,I]=M*A[Q,E]*32.8/(32.6+A1)
260 IF (K=1) THEN 320
270 U1=(M+(C*(1-F[J,I]/1000)))*A[Q,E]*32.8/(32.6+A1)
280 IF (F[J,I]/1000 >= 0.97) THEN 300
290 GOTO 320
300 K=1
310 U1=0
320 IF (T1 >= 4) THEN 430
330 PRINT T1,B[J,I]*100/145,P[Q,E],U1*100/145
340 Q=Q+1
350 IF (Q=257) THEN 370
360 GOTO 400
370 Q=1
380 E=2
390 GOTO 230
400 T1=T1+0.01
410 NEXT J
420 NEXT I
430 STOP
440 END
```

APPENDIX B.

REQUIRED INPUT PARAMETERS FOR DETERMINING THE FRACTION OF PROPELLANT BURNED

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INPUT PARAMETERS

1. U1, internal volume of primer, (m^3)

2. V1, chamber volume, (m^3)

3. M, mass of the projectile, (kg)

4. C, mass of the propellant charge, (kg)

5. GAM, propellant ratio of specific heats

6. RHO, propellant density, (kg/m^3)

7. AREA PROJ, area of base of projectile, (m^2)

8. ETA, propellant co-volume, (m^3/kg)

9. F, propellant force constant, (J/kg)

APPENDIX C.

REQUIRED INPUT PARAMETERS FOR DETERMINING CAVITY PENETRATION

INPUT PARAMETERS

1. A1, bore area, (cm^2)

2. B1, projectile base position relative to breech face of gun, (m)

3. C8, cavity initiation position relative to breech face of gun, (m)

4. R1, cavity radius, (m)

5. S1, projectile start of motion, (ms)

6. T2, Taylor coefficient

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